Students will review scientific infographics to test their understanding of the role, contribution, and limitations of climate models in helping us understand Earth’s past, present, and future climate system.

What you’ll need:
- A copy of the Student Backgrounder on Modeling for each student
- A laminated set of informational graphics for each small group of students

Directions:
After lessons on Earth’s climate system and climate change have been presented, introduce the concept of climate modeling to students.

1. Survey students’ understanding of what a climate model is at the start of the lesson, then provide each student with a copy of the Student Backgrounder to read as a precursor to a more detailed class discussion about climate models and their evolution in the past half century.

2. Record the questions students have about modeling that are not answered in the Student Backgrounder. Divide the questions among students who will research answers and report back to the group. To assist them with their research, provide the modeling references found later in the activity.

3. Ideally, have students play a few rounds of Climate Modeling Bingo found on the Spark – UCAR Science Education website as a review for necessary vocabulary on modeling in advance of the Get the Picture activity.

Begin Activity:
1. Tell students that they will be tasked with analyzing infographics about Earth’s changing climate and/or climate models.
2. Let them know that their understanding of climate models will be assessed by their answers to the true-and-false questions and their ability to discuss and defend them. Rotate among the various groups to get a sense of student understanding and any areas of difficulty.
3. After groups have reviewed their set of infographics, bring the class back together to discuss their true and false answers collectively. Ask students also about the visual representation of the content. Were the infographics more effective and efficient than words alone? Which graph, if any, warrants further clarification? Ask questions that require students to use vocabulary relevant to a discussion of climate change and climate models.
4. End the lesson with an open conversation about what students think the future might hold in terms of the climate system, the role that models play in helping anticipate future possibilities, and the limitations of models. At the end of the discussion, make sure to convey that while the challenge can seem overwhelming, many individuals in communities, states, governments, and countries have begun to take action to address the world’s climate change problem.

Reflection and Assessment
Models are an integral part of our lives but also to science. Climate models are important mathematical tools that give scientists a virtual world in which to experiment and, thus, advance knowledge of Earth’s climate system. Because climate models help us understand a very complex climate system that people depend upon, it’s important that students understand the value and limitations of mathematical climate models and their relevance in helping us address difficult global challenges.

For Teachers:

Student Learning Objectives
Students will:
- read and interpret graphs
- understand the role, contributions, and limitations of climate models
- know that climate models steadily improve and that discoveries are needed and ongoing

Class time
- Two 50-minute class periods, the first to introduce climate models and the activity, and the second to review and reinforce the lesson’s learning objectives

Grades
- 9th - 12th grade

National Science Standards
- Energy in the Earth system
- Understanding about science and technology
- Science and technology in local, national, and global challenges
- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives
- Evidence, models, and explanation
- Change, constancy, and measurement

Standards for School Mathematics
- Data Analysis and Probability

Answers to True and False Questions
Figure 1: True, False, False, True
Figure 2: True, False, True, True
Figure 3: True, True, False, True
Figure 4: False, True, True, True
Figure 5: True, False, True, True
Figure 6: True, False, True, True

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What is a climate model?
Climate models are virtual laboratories that scientists use to conduct research into Earth’s past, present, and future climate. The information that climate models provide help us to understand changes in Earth’s climate system over time scales spanning seasons to centuries and longer. They provide the only available experimental laboratory for global climate and for projecting future changes. These models use mathematical representations of the physical, chemical, and biological processes in the Earth system. Today’s global climate models are actually comprised of four separate submodels of Earth’s atmosphere, ocean, land surface, and sea ice, then one central coupler component combines them.

Models that focus on only a portion of the world’s climate are called regional climate models and help predict events such as flooding and heat waves. While models are an important part of many areas of everyday life, today’s climate models are among the most sophisticated simulation tools created by mankind.

The structure and design of a climate model includes 3D “grid cells” that cover a set location over the globe in which equations are solved. These equations represent laws of physics that replicate components of Earth’s climate system that are eventually transferred into computer code. The size of the cells can vary as shown in the figure below, and size determines the model’s resolution. Because one set of equations is calculated in each grid cell, models that use larger cells produce less detail, while models that use many smaller cells result in a higher resolution and more realistic climate representation. Models also incorporate the element of time, simulating what happens within each grid cell at one time, then stepping forward in consistent increments of hours, days, months, or years. Shorter time steps require more computing power. Millions of calculations are performed to create a climate simulation. To run these computationally intensive models, supercomputers with thousands of processors and petabytes (over 1000 trillion bytes) of storage are necessary.

How do climate models differ from weather models?
Both weather and climate models were developed from a common heritage rooted in fundamental physics, but Numerical Weather Prediction models (NWP) cover only regional areas of the world versus the entire globe. They also differ from global climate models in that they use a much smaller resolution or grid-cell size (i.e. 5 km vs 200 km) so that they can forecast small changes in weather over short periods of time from a few hours to days. Weather models are highly sensitive to initial conditions that represent the present weather conditions. Because weather is a chaotic system, the forecast will diverge from reality in a short amount of time. That is why forecasts are made for only ten days or so.

Climate models, on the other hand, are less dependent upon initial conditions and instead must deal with large scale disturbances to climate such as external forces that warm or cool the planet. GCMs are concerned with the statistics of weather that are not as variable over large periods of time, rather than precise short-term forecasts.

Why do we trust climate models?
We trust models because they can be tested and evaluated to see how accurately they imitate past climate. This is called hindcasting. Accurate hindcasts add increased confidence in the models ability to make future projections. If climate models could not capture the primary processes and patterns we see seasonally and annually, or if they fail to respond to known climate forcings like volcanoes, then the model designers would be required to return to the drawing board. It is important to realize, however, that climate models do have limitations. They will never produce perfect projections of the future, only approximations because key information needed to make a climate projection can never be known fully, such as humans’ ability to reduce greenhouse gases that trap heat. Likewise, not all processes that are part of the climate system are fully understood and represented in the model. Uncertainty will always be present, but scientists consult with experts to quantify what is likely. There is a saying attributed to mathematician George E. P. Box that says that models are always wrong, but some are useful. As counterintuitive as that might sound, it is a true statement. That is why climate change models aren’t run simply once but multiple times, and often across many different climate models. This is called an ensemble. Model ensembles provide a range of outcomes that are averaged, rather than one exact single projection of a climate variable.
The complexity of global climate models has increased enormously over the last four decades, as shown in this graphic. The most powerful models, such as the Community Earth System Model (developed by scientists at the Department of Energy and NCAR with colleagues at other organizations), now have the capability of simulating a broad range of atmospheric processes, such as the impact of marine ecosystems on the atmosphere. Source: UCAR

When were climate models developed and how have they changed over time?
Climate models began in the United States in the mid-20th Century as computers evolved. Scientists set out to build a model using equations within a computer that represented pre-defined laws of physics and fluid dynamics that they hoped would recreate Earth's atmospheric circulation. Initially progress was slow, but as computer technology advanced and more scientists joined the effort, progress accelerated.

Over a half century later, today's Global Climate Models (GCM) are designed using computer-based mathematical expressions as before, however, they are exceedingly more complex. They no longer only reproduce global circulation, but also feedbacks of climatic processes due to increasing greenhouse gases, changing ocean currents, and the model's response to various climate forcings. Nearly all known components of Earth's climate system are now represented in global climate models thanks to the efforts of many experts in science, mathematics, engineering, and computer science.

What do the various climate models agree upon? Where do they disagree?
Global climate models have grown in complexity and quality over past decades, and the most sophisticated models agree on the big picture of climate change. This includes the rough amount of warming expected and the idea that poles will warm faster than other locations. Today's best climate models are now able to reproduce the climate of the past century and known climate patterns. NCAR's climate model accurately reproduces Earth's climate from 1870 to 2000, the irregular cycle of the El Niño phenomenon in the Pacific Ocean, and the ebb and flow of sea ice in the polar regions.

Models disagree because of natural variability in the climate system, differences in projections or estimates of climate forcings that warm or cool the climate, and feedbacks. For instance, small particles in the atmosphere called aerosols help create clouds that impact climate, however, there is much uncertainty around aerosols. While climate models will never be entirely accurate, it is important to realize their value to science and society, and to helping us understand the Earth's climate system.

What are some of the big climate change challenges that involve climate modeling?
As noted in a recent National Academy of Sciences report, the big questions regarding Earth's climate that models help us address are:
• How much will the planet warm this century due to rising GHG?
• How will climate change on regional scales and how will this affect the water cycle, water availability, and food security?
• How will climate extremes change?
• How quickly will sea level rise?
• How will Arctic climate change?
• What is the potential for abrupt change in the climate system?
• How will marine and terrestrial ecosystems change?
• How will society respond to and feed back on climate change?
• Can the evolution of the climate system over the next decade be predicted?

There are less than two dozen respected GCMs in use around the world today. In the United States, global climate models are developed, evaluated, analyzed, and constantly improved at large governmental or national labs including NCAR, NOAA, and NASA.
TRUE OR FALSE?

According to this graph, **natural factors** that cause climate to change such as the Sun and volcanoes, cannot explain the increasing trend in **global surface temperature** observations from the early 1960s to 2000.

When the role of both natural and **human-caused climate forcings** were included in the climate model (red line), then recent warming as shown by observations (black line) were replicated perfectly by the model.

The wide shaded areas of color exist in the graph to highlight the graph’s blue and red lines and make the graph more aesthetically pleasing.

According to the above graph, attribution for climate change since 1965 is primarily the result of anthropogenic (human-made) forcings.
FIGURE 2: Annual-mean precipitation in the western United States simulated by a climate model with three different resolutions (300, 75, and 50 km) and compared with observational data (VEMAP) at 50-km resolution. Source: Walter, 2002 and Duffy et al., 2003 in A National Strategy for Advancing Climate Modeling, National Academy of Sciences, 2012.

TRUE OR FALSE?

The **resolution** of the two graphs in the bottom row both represent precipitation at a certain point in time in the western United States at a **resolution** of 50 km.

More detail is captured in a model when the **resolution** used spatially is larger. Larger spatial areas allow for a greater number of calculations to be performed and, thus, better represent the flow of energy in the Earth system.

Areas of no precipitation existed in the above example that were captured in the model using a 300-kilometer **resolution**. Interestingly, the 50-kilometer **resolution** model did not accurately capture these areas, but overall it still was more accurate.

Models rarely if ever perfectly predict or replicate the duration and spatial distribution of rain, but the models would improve greatly if a 1-kilometer **resolution** model was used.
TRUE OR FALSE?

All models that were used to project minimum annual Arctic sea ice in the above graph show a declining trend in Arctic sea ice until at least 2050.

Model projections of minimum annual Arctic sea ice above, paint a rosier picture than what is actually occurring.

Annual measurements of the Arctic sea ice minimum have gone up and down from year to year for decades, but this annual variability will not likely continue.

Based on observations of the loss of Arctic sea ice shown by the gold line, the melting will result in significant sea level rise due to the addition of fresh water into oceans.
Figure 4

Change in Global Average Surface Temperature
compared to 1961-1990 average

- Climate of past 1000 years (paleoclimate data)
- Climate of past 1000 years (NCAR model)
- Climate of past century (observations)
- Future climate (NCAR model simulations)

TRUE OR FALSE?

The future state of Earth's climate – as shown in the model simulation – is full of certainty. The probability that Earth will warm by at least 1.8 °C, for example, is definite.

Scientists run the climate models under different future scenarios based on a range of projections including estimated future actions to reduce (mitigate) green house gases (GHG). That is why the graph shows four possible future states.

Even observational data in the graph is not free of uncertainty. Uncertainty is an inherent part of modeling, climate simulations, and projections.

The shaded areas in the graph illustrate the degree of uncertainty in the temperature anomaly data for various years. The range of variability was produced by running the model multiple times (an ensemble), and graphing both the mean and the spread from the various projections.
TRUE OR FALSE?

The ultimate aim of climate modeling is to model the whole of Earth’s climate system as best as possible, including continuously taking into account interactions and feedbacks among components. That is one reason why they’ve grown in complexity.

According to the diagram, land surface models were the very first steps in building today’s climate models.

Additional climate components that have been added to climate models are actually models themselves that must be evaluated and assessed before being added as part of the established climate models.

The greater the sophistication and complexity of climate modeling, the greater the need for many detailed measurements from observations to test whether the model has imitated reality accurately.
A consequence of the volcanic eruptions Krakatau, Santa Maria, Agung, El Chichon, and Pinatubo, was a cooling of global surface temperature for approximately one to two years following each eruption.

Overall, there is no positive or negative **correlation** between CO2 levels and global average surface temperatures.

A climate model is run multiple times to produce the statistics of Earth’s climate system over a period of a century or more most often. A **model ensemble** produces variability and a mean rather than precise weather events.

Data for each year is graphed in comparison to the 1961-1990 global average surface temperature represented as 0°C in the graph. Each year’s **deviation from the mean** is shown. These deviations from the mean are called **anomalies**.